23rd IAA SYMPOSIUM ON SPACE DEBRIS (A6)
Interactive Presentations - 23rd IAA SYMPOSIUM ON SPACE DEBRIS (IP)

Author: Mr. Guo Chen
Beihang University, China

Dr. Yu Zhang
Beihang University, China
Mr. Chaoqun Zhang
Beihang University, China
Mr. Hongxiang Jiang
Beihang University (BUAA), China
Mr. Xiaodong Wei
School of Astronautics, Beihang University, Beijing 100191, PR China, China
Prof. Jihao Yin
Beihang University (BUAA), China

AN AI-BASED FRAMEWORK FOR SPACE DEBRIS DETECTION AND LOCALIZATION IN CISLUNAR SPACE TOWARD ENHANCED SITUATIONAL AWARENESS

Abstract

The cislunar space has become a critical region for scientific exploration and economic development, fueled by increasing lunar missions and international collaborations. As initiatives like China's "Cislunar Space Economic Zone" and NASA's "Artemis" Program rapidly expand the number of artificial objects in this region, maintaining space situational awareness (SSA) is essential for ensuring the safe operation of spacecraft. Detecting small and dim space debris—crucial for preventing collisions—presents significant challenges due to weak signals, limited visual features, slow apparent motion, and interference from lunar illumination. These complexities underscore the growing need for artificial intelligence (AI) methods capable of processing and analyzing large-scale data efficiently for space debris monitoring in cislunar space.

Conventional detection methods face significant challenges in cislunar space, largely due to the low signal-to-noise ratio (SNR) of distant debris and interference from the bright lunar background. The subtle motion and lack of distinct features further complicate detection, and many existing techniques overlook temporal information, limiting their ability to reliably track and identify dim debris in such conditions.

In this work, we propose OSDNet, an offset-sensitive deformable 3D convolutional network with an SNR-guided attention mechanism designed for low-SNR environments. Unlike traditional methods that process single images, OSDNet operates on sequential data, detecting subtle motion cues often imperceptible in single frames. The deformable 3D convolution adjusts spatial and temporal sampling based on target movement, capturing the temporal variations needed to detect slow-moving debris. The SNR-guided attention module refines heatmaps and improves center point localization by dynamically weighting features according to SNR, enhancing dim debris while reducing background noise.

Experiments conducted on simulated sequential observation datasets generated with Systems Tool Kit (STK), covering both cislunar and Earth-orbiting space debris, demonstrate that our framework performs well in terms of precision, recall, and F1 score. OSDNet excels at detecting small, distant debris while maintaining computational efficiency, making it ideal for real-time SSA applications and contributing to safe operations in the increasingly congested cislunar environment.

This study introduces an advanced AI-driven framework for space debris monitoring, with broad applicability to various SSA tasks, including on-orbit servicing and early-warning systems. By leveraging deep neural networks, our solution significantly enhances the ability to detect and track space debris under complex conditions. These innovations pave the way for future advancements in AI-driven SSA, contributing to the safe and sustainable management of the cislunar environment.